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Indian Standard

CODE OF SAFETY FOR RADIOCHEMICAL LABORATORY

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
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Indian Standard
CODE OF SAFETY FOR RADIOCHEMICAL LABORATORY

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Indian Standard
CODE OF SAFETY FOR RADIOCHEMICAL LABORATORY

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 2 August 1968, after the draft finalized by the Chemical Hazards Sectional Committee had been approved by the Chemical Division Council.

0.2 Radioisotopes are increasingly employed in medicines, agriculture and industry and in research laboratories. The maximum permissible concentrations of radionuclides in air and water are in almost all cases, excepting natural uranium, of orders of magnitude lower than the maximum allowable concentrations of non-active chemical isotopes. This, coupled with the characteristic radiotoxicity and difficulties of detection by conventional methods, makes it necessary that elaborate precautions are taken in the design and layout of radiochemical laboratories and in the handling, storage and disposal of radioactive materials.

0.3 The potential injuries due to radiation may be reduced to a minimum if all the safety instructions prescribed for the purpose are followed to the fullest extent. This is only possible if the characteristic of the radioactive material, nature of the hazards involved, purpose underlying the safety instruction and the function and uses of protective equipment are fully understood.

0.4 Radiation science is a very highly specialized field and a considerable amount of sustained research is being carried out throughout the world. As such concept and definitions change rather rapidly. Subject to this limitation, this code is based on best current opinion available on the subject. In the preparation of this code of safety, the following publications, in particular, have been freely consulted:

Report of International Commission on Radiological Protection Committee II on permissible dose for internal radiation 1959, Pergamon Press, New York.

International directory of radio isotopes, Vol I, published by International Atomic Energy Agency, Vienna.

International Commission on Radiological Protection (ICRP) Publication No. 6 (Amended and Revised 1962, 1964), Pergamon Press, New York.

Recommendations of the International Commission on Radiological Protection. (Adopted September 17, 1965). ICRP Publication No. 9, Pergamon Press, New York.

A basic toxicity classification of radionuclides; Technical Report No. 15, International Atomic Energy Agency, Vienna, 1963.

Basic safety standard for radiation protection, International Atomic Energy Agency, Vienna, 1967.

Radioactive products, Bhabha Atomic Research Centre, Trombay, Bombay (AS).

Manual of radiation protection in Bhabha Atomic Research Centre, Trombay, Bombay (BARC/223); 1965.

Report of Committee V on the handling and disposal of radioactive materials in hospitals and medical research establishments, 1964, Pergamon Press, New York.

0.5 Safety code for industrial radiographic practice (IS : 2598-1966) has already been published which gives in detail safety aspects concerning the use of ionizing radiation for industrial radiography.

0.5.1 For prevention of chemical accidents, which may also occur in a radiochemical laboratory or which may lead to exposure due to radiation, IS : 4209-1966* may be consulted.

1. SCOPE

1.1 This code recommends measures that should be adopted to prevent harmful over-exposure to radiation in a radiochemical laboratory handling small amounts of radioactive materials during normal operations. It describes important characteristics of radioactive materials, nature of hazards, design requirements of laboratories and other essential information for protection against radiation.

2. HAZARDS

2.1 The hazards that are usually encountered in using radioisotopes arise from:

a) external exposure, and
b) internal exposure.

2.1.1 External exposure may be attributed to sources outside the body. External exposure from alphas and betas is mostly limited to the first few millimetres from the surface of the skin and results from spills and contamination.

2.1.2 Internal exposure results when radioactivity finds access inside the body. The hazard arises when the activity deposits in the organs and irradiates seats of deposition. Alpha emitters are considered most toxic under this class of exposure.

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*Code of safety for chemical laboratories.

3. BIOLOGICAL EFFECTS OF RADIATION

3.1 The biological effects of ionizing radiation are described at length in several treatises and are fairly well known. All ionizing radiations interact with tissue in such a way as to produce deleterious effects which are qualitatively similar. But quantitative differences arise from the fact that the total energy per gram imparted to the tissue which is irradiated is not the only factor to be considered. A heavy particle produces many more ions per cm length of its track than a beta particle. As a result, different radiations have relative biological effectiveness, which is indicated by ' Quality Factors ' (QF) to denote Linear Energy Transfer (LET) factors. Absorbed doses will have to be multiplied by QF to express on a common scale radiation exposure incurred by persons due to all ionizing radiations. For internal exposure QF should be taken as 1 for β^-, β^+, gamma and X radiation and conversion electrons (except in case of β^-, β^+ and e^- radiations with maximum energy E_m 0·03 Mev for which QF is taken to be 1·7), 10 for alpha particles and 20 for fission fragments and for nuclei recoiling during alpha emission. For a detailed discussion on QF reference may be made to ICRP Pub-6.

3.2 The biological effects from radiation exposure produced either through single active exposures or through chronic exposures are classified as follows:

a) *Somatic* — affecting the living cells responsible for the maintenance of body functions, and

b) *Genetic* — affecting the germ cells which are responsible for the propagation of genetic characteristics.

3.2.1 Massive acute exposures, which are likely to induce radiation sickness or even death, are to be guarded against in dealing with fissile materials and in operating reactors.

3.3 It is chronic exposure that is to be guarded against in tracer laboratories and in working with low level activities in radiochemical installations. It is internal exposure primarily resulting from inhalation, ingestion and contamination of wounds that one has to specifically guard against. Chronic exposures have been shown to have appreciable influence in reducing the life span of the individual and increasing the incidence of leukaemia. Cataract of eyes, induction of bone tumours, aplastic anaemia are some of the other observations attributed to chronic exposures.

4. MAXIMUM PERMISSIBLE EXPOSURE LIMITS

4.1 The permissible dose for an individual is stated to be that dose accumulated over a long period of time or resulting from single exposure, which in the light of present knowledge carries a negligible probability of severe somatic or genetic injuries; it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable to the individual by competent medical authorities.

4.1.1 In any organ or tissue the dose equivalent due to occupational exposure shall comprise that contributed by external and internal sources, resulting from the circumstances imposed by the occupation. It shall not be held to include the dose from any medical exposure as patients, from exposure to natural background radiation or from other exposures received by the individual as a member of the public.

4.2 The maximum permissible dose to the whole body, gonads or red bone-marrow of an individual shall be 5 rems in any one year. Provided the total dose in any one year does not exceed the maximum permissible dose (subject to restrictions in **4.2.1**), a worker may receive in a quarter of a year a dose to the whole body, gonads and the red bone-marrow not exceeding 3 rems. A dose of 3 rems may be received as a single dose within a quarter of a year, but this shall be avoided as far as practicable. For providing flexibility, the maximum permissible total accumulated dose for exposure involving whole body, gonads and red bone-marrow at any age over 18 years shall be governed by the relation:

$$D = 5 (N - 18)$$

where

D = tissue dose in rems, and

N = age in years.

The maximum permissible doses recommended are:

	Quarterly Limit rems	*Yearly Limit* rems
a) Gonads and red bone-marrow, and in the case of uniform irradiation, the whole body	3	5
b) Any single organ (including lenses of the eye) excluding gonads, bone-marrow, thyroids, skin and hands, forearms, feet and ankles	8	15
c) Bone, thyroid, skin of the whole body (excluding skin of hands, forearms, feet and ankles)	15	30
d) Hands, forearms, feet and ankles	40	75

4.2.1 There are also special cases listed below where exceptions to the application of the above procedure may be desirable for practical reasons.

4.2.1.1 *Previous exposure unknown* — If the dose previously accumulated in radiation work by the worker over any given period is not known, it shall be assumed that the worker has received the currently recommended maximum permissible dose in each year of that period.

4.2.1.2 *Persons starting work at an age less than 18 years* — When a person begins to be occupationally exposed at any age of less than 18 years, the dose equivalent to the gonads and the red bone-marrow should not exceed 5 rems in any one year under age 18, and the dose accumulated to age 30 should not exceed 60 rems.

4.2.1.3 *Exposure of women of reproductive capacity and pregnant women* — In circumstances where women of reproductive capacity are involved then the permitting dose to the abdomen is limited to 1·3 rems in a quarter corresponding to 5 rems per year delivered at an even rate. Under these conditions, the dose to an embryo during the critical first two months of organogenesis would normally be less than 1 rem. It is recommended that when a pregnancy has been diagnosed, arrangements should be made to ensure that the exposure of the woman be such that the average dose to her foetus, accumulated during the remaining period of pregnancy, does not exceed 1 rem.

4.3 Exposures of the Members of the Public — It is not advisable that members of the public should receive exposures from operations. Such exposures take place through accidental or indiscriminate releases to the public environment. Dose limits are described for exposures of public rather than maximum permissible limits. The annual dose limits for members of the public shall be one-tenth of the corresponding occupational maximum permissible doses.

5. CLASSIFICATION OF RADIOISOTOPES

5.1 Several considerations go into the classification of the radioisotopes according to relative radiotoxicity. Appendix A gives a recent classification of the different radionuclides according to relative radiotoxicity per unit activity. The classifications into Groups 1 to 4 correspond to the terms high toxicity, medium toxicity (upper sub-group A), medium toxicity (lower sub-group B), and low toxicity respectively.

6. RADIATION SOURCES

6.1 The radiation sources in use may be classified as:

a) *Sealed Sources* — which do not contribute to contamination or internal hazard, and remain a primary source.

b) *Open Sources* — which are used for secondary preparations through dilutions, labelling, etc.

6.1.1 *Sealed Sources* — Sealed sources are employed in a number of fields, such as teletherapy, interstitial therapy, industrial gamma radiography, thickness gauging, static eliminators and for calibration purposes. Co-60, Ir-192, Cs-137, Sr-90, Tl-204, etc, are some of the more common sources which are industrially used. Such sources are normally sealed in capsules to prevent the escape of the radioactive material and should be ensured against breakage or defective sealing. In case of properly sealed sources, the hazard arises only through external exposure, and against this the greatest precaution should be used.

6.1.1.1 *Choice of sealed sources* — The activity of the source should be as low as possible and not in very much excess of the requirements, with due regard to its half life and duration of use. The radioactive material inside the sealed container should be of low toxicity, and in such chemical and physical form as to minimize dispersion or ingestion, in case of rupture of the container. Sealed sources should have clear markings indicating the nature and quantity of the source activity. These sources should be periodically checked up for any contamination or leakage, particularly in case of radium whose daughter product radon is a gas which could be quite hazardous when inhaled. A recommended test is to scrub the dry container with a dry filter paper sponge and to count the activity. Mechanically damaged or corroded sources should be immediately placed in suitable containers and sealed.

6.1.1.2 *Precautions in the use of sealed sources* — The basic objective of all radiation protection measures is to prevent handling personnel from receiving radiation doses in excess of the maximum permissible levels of exposure recommended. This is achieved by a suitable combination of the following factors:

a) *Time* — By limiting the time of exposure;

b) *Shielding* — By the use of adequate shielding in *between the active source and the worker*; and

c) *Distance* — By maintaining a maximum possible distance *between the source and the worker*, by using long forceps and remote handling equipment.

By making use of these factors in appropriate combination, radiation exposure to personnel not only engaged on actual work, but in the surroundings also, could be reduced to the minimum.

6.1.1.3 It is very important that while working with any sealed radiation source, adequate shielding should be provided and the adequacy should always be tested by direct measurements. Precautions should be taken to guard against any scattered radiation around the primary protective shielding. The eyes, face and body may be protected from beta rays by transparent plates of perspex of moderate thickness. Protection against gamma rays should be achieved by screening the source with adequate shielding of lead which should be as near the source as possible. The lead bricks used for shielding sources should overlap to prevent penetration of radiation through gaps. In addition to lead, concrete and marble also offer adequate protection against gamma radiation, but lead is the most convenient.

6.1.1.4 Forceps used for handling these sources should be as long as practicable and should grip the source with minimum force exerted by the fingers. These forceps should be light in weight and should have grips notched or grooved in a way to hold the sources securely. Transparent plastic hand shields of sufficient thickness attached to the forceps would be an added protection against the most energetic betas, if unshielded beta emitters are being used. The time of handling these sources should be minimum possible, if unshielded radiation sources are being used. For pipetting solutions of very high activity and presenting over exposure hazards in handling, remote handling pipette should be utilized over the shielding wall.

6.1.1.5 Vices, chucks or similar arrangement should be provided at the protective barriers, to facilitate handling of sources. They should be designed against excessive clamping pressure which will lead to damaging the sources. A spring loaded ratchet or slipping clutch mechanism would prove useful.

6.1.1.6 Some of the regulations to be observed in the application of the sealed sources are given briefly below (for detailed code of safety for industrial radiographic practice, refer to IS : 2598-1966*):

a) *Industrial gamma radiography* — The controlled area should be clearly marked with instructions restricting entry to unauthorised personnel. Light or audible signals or both should be provided during irradiation. The radiographic set-up should be completed before starting the irradiation. Any radiographic work requiring removal of the sealed source from shielding container should be preceded by adjustments with a dummy capsule. The removal of the source from the shielding container should be done by automatic means or remote handling. After return to the container, the shielding should be verified by monitoring.

b) *Thickness gauges, static eliminators and similar devices using sealed sources* — Wherever possible sealed sources should be installed or shielded in such a way that personnel installing or maintaining the sealed source should not receive exposure in excess of the recommended maximum levels of exposure. Radioactive symbols should be put up permanently on such devices. In case of loss or breakage of the source, the radiological health and safety officer should be notified immediately.

6.1.1.7 Teletherapy and interstitial therapy installations in medical departments need elaborate planning and form a separate subject altogether.

6.1.1.8 *Method of use of sealed sources* — Source should be properly stored and inventories maintained. If any person has reason to believe that a source has been lost he should report immediately to the radiological health and safety officer. All sources should be manipulated in such a way as to minimize exposure of personnel and people in adjacent area. Area of particular hazard should be cordoned after marking off. Any semi-shielded beam or scattered beam should be clearly indicated, and area monitored to assess the radiation fields. Sealed sources, when practicable, should be used in enclosed installations and should never be touched with hand. In addition to adequate shielding, limiting the working time also helps to make the exposure as short as possible and for this dummy runs should be performed beforehand. These protection measures require careful planning and proper application of protection principles.

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*Safety code for industrial radiographic practice.

6.1.2 *Unsealed or Open Sources* — The open sources offer a comparatively larger scope of work and are employed in tracer studies and preparation of labelled compounds. They present problems of safety in handling and are a potential source of contamination in the laboratories. In manipulating an unsealed or open radioactive source great care should be exercised towards minimizing the chances of entry into the body as a result of ingestion and inhalation of air-borne particles and absorption through contact with contaminated surfaces. The hazards will arise in general through contaminated hands, smoking and mouth pipetting, glass blowing, etc, or from inhalation of air-borne radioactivity. When the hazards due to ingestion and inhalation are negligible (as in the case of well sealed sources) the risks in handling radioisotopes will depend essentially upon the effects of external beta and gamma radiation.

7. CLASSIFICATION OF LABORATORIES

7.1 The types of laboratories needed for handling different quantities c open sources of radioisotopes depending upon the relative radiotoxicity ar given in Table 1.

TABLE 1 CLASSIFICATION OF RADIOCHEMICAL LABORATORIES

LEVEL OF RADIOTOXICITY OF ISOTOPES*	TYPE OF LABORATORY REQUIRED FOR LEVELS OF ACTIVITY		
	Type 1	Type 2	Type 3
(1)	(2)	(3)	(4)
Group 1	$<10\ \mu Ci$	$10\ \mu Ci$-1 mCi	>1 mCi
Group 2	<1 mCi	1 mCi-100 mCi	>100 mCi
Group 3	<100 mCi	100 mCi-10 Ci	>10 Ci
Group 4	<10 Ci	10 Ci-1 000 Ci	$>1\ 000$ Ci

*See Appendix A.

7.1.1 Modifying factors may be applied to the quantities mentioned in the last three columns of the above table, according to the complexity of the procedures to be followed. The following factors have been suggested which should be used with discretion:

Procedure	*Modifying Factor*
Storage (stock solutions)	× 100
Very simple wet operations	× 10
Normal chemical operations	× 1
Complex wet operation with risks of spills, simple dry operations	× 0·1
Dry and dusty operations	× 0·01

7.1.2 At the present stage of development and utilization of radioisotopes in the country, Type 3 laboratories (Table 1) are not likely to come up outside the Department of Atomic Energy and Allied Units. However, there are a couple of laboratories in the country which can be designated as belonging to the Type 2; Type 1 laboratories are expected to be quite common in the medical and agricultural institutions, industrial establishments and universities. Types 1 and 2 laboratories are described in **7.2** and **7.3**.

7.2 Type 1 Laboratory

7.2.1 For manipulation of small amounts of radioactivity (as quoted in Table 2) a modern conventional chemical laboratory with a few modifications may be used. However, while converting any such laboratory to a radioactive Type 1 laboratory, judicious consideration be given to (a) radiation safety, (b) efficiency of operation, (c) economy, and (d) convenience. Some of the salient features requiring attention for this type of laboratory are outlined below:

a) *Layout* — As far as possible, active laboratories should be designed in such a way as to segregate from other inactive laboratories. Working space in this type of laboratory should be allotted on generous scale as compared to a normal chemical laboratory. Sufficient storage space should be provided for stocking radioactive solutions. Washing facilities in general are adequately complied with by use of the ordinary laboratory sinks with a smooth white glass finish without cracks. The taps should be workable by elbow, foot or knee so as not to contaminate them by hands or gloves. The discharge of liquid radioactive waste should be limited to one or two drains. The drains if possible should be of plastic or polyethylene pipe which could be easily repaired. The drains should be properly planned to pass through areas away from work places and should lead to sewers or collecting carboys or tanks.

b) *Floors, walls and working surfaces* — The floors and working surfaces should be covered with linoleum and work benches should be suitably equipped with non-absorbent tops and with disposable covers. All working surfaces (including the fume hood) should be strong enough to support the weight of the necessary shielding material (lead, iron) against gamma radiations. Floors should be cleaned by wet mopping and should not be swept dry. Walls and ceilings should be finished with a non-porous washable surface, such as a good hard gloss paint.

c) *Fume hoods* — In operations where gaseous release or reactions at elevated temperatures are involved, use of a fume hood is necessary. As far as possible, handling of active solutions shall be carried out in fume hoods. The fume hood exhaust system should be sufficient to produce a velocity of about 30 linear metres per minute across the opening of the fume hood. This should give efficient clearance of the laboratory air at the rate of about 10 air changes per hour. Even at the maximum permissible activity levels in a Type 1 laboratory, it is sufficient to discharge the exhaust air through ducting to the outside of the building at a point above roof level or at least not immediately adjacent to windows or air intakes. It is not necessary to filter the air at these low levels. Due care should be given, when considering the design and erection of exhaust ducts, towards ease of replacement as well as minimizing the spread of contamination within buildings during the dismantling operations. For example, the duct length could be as short as possible and single piece and the exhaust fan should be mounted on the outside of the ducting to reduce contamination of the motor and to make it more accessible for maintenance purposes. A piece of ducting needing repairs after long run is best discarded as radioactive waste; this prevents spread of contamination in workshop and other areas. Fume hoods should produce a regular flow without any eddies. The speed of the air flow should be such that there can be no escapes of air into the work place from the fume hood under typical operating conditions.

7.3 Type 2 Laboratory

7.3.1 This laboratory is intended to be used for handling activities in the range of the order shown in col 3 of Table 2. Some of the salient features common to this type of laboratory are as follows:

a) *Layout* — As far as possible active laboratories should be designed and used so as to segregate widely different levels and types of activity. Entry into a laboratory or exit out of it should always be through change rooms equipped with personnel monitoring and decontamination facilities. Counting rooms should be separate, conditioned to 25°C and 55 percent humidity and away from rooms for storage and working with radioactive material to avoid contamination and high background. Working space in this type of laboratory should be allotted on generous scale as compared to a normal chemical laboratory. Ample storage space should be provided for radioactive samples.

b) *Plumbing facilities* — In high active sections, drains which are to handle radioactive effluents shall be an entirely separate system. However, in practice the liquid wastes are collected and stored in suitable containers before effecting controlled discharge into the environment and hence there is no need for a separate drainage system generally. The discharge of low level liquid wastes should be limited to one or two drains. These drains, if possible, should be of plastic or polyethylene pipe which could be easily repaired. The drain should be properly planned as to pass through areas away from work places and should lead to sewers or collecting carboys or tanks.

c) *Washing facilities* — For cleaning purposes, the usual laboratory sink, without any sharp corner, or cracks, will suffice; stainless steel sinks offer certain advantages over soapstone or porcelain sinks. If the discharge of active wastes is through the sink, it is preferable to have a cup sink since this would present a relatively small area for contamination accumulation. The taps should be workable by elbow, foot or knee, so as not to contaminate them by hands or gloves. A plastic or glass sheet should be fixed to the side of the sink which is closer to the worker to avoid spillage of the active liquids on the worker.

d) *Materials* — The design of laboratories for radioactive work should be such that they can be easily kept clean. Places where dust can accumulate are kept to a minimum. Floors should have smooth continuous, non-absorbent surfaces and should be made of materials that may easily be cleaned, and may also be replaced, if necessary. Floors are best covered with good-quality linoleum cemented at the joints and edges and well polished with wax. Any minor contamination may be removed with wax, and in case of gross contamination the linoleum may be readily replaced. Wood and concrete surfaces are highly disadvantageous as floor surfaces because they are almost impossible to be decontaminated and are quite expensive to be replaced. They should be linoleum covered. Corners between walls and floor, or walls and ceiling should be rounded off. Walls and ceilings should be finished with a non-porous, washable surface of coating, such as obtained with good hard gloss paint. However, where heavy contamination is expected, it is advisable to use a strippable paint.

e) *Bench tops* — These may be of hard wood thoroughly polished or Formica or rubber sheet with a smooth surface although stainless steel lining is sometimes recommended. The working surface should always be covered with disposable absorbent paper or plastic coated linoleum paper. It has been suggested that the bench tops be covered with special paper which are absorbent on one side and waterproof on the other. In some cases, where protection to external radiation is achieved with a concrete bench top, it is necessary to paint the surface with gloss paint or strippable paint.

f) *Drip trays* — These are used to minimize risks from spills.

g) *Fume hoods* — Fume hoods are usually constructed of wood and glass, the former being covered with a good hard gloss paint. In fume hoods required for high activity work, a strippable paint, particularly inside the hood is advocated. Depending upon the type of work, a layer of replaceable absorbent waterproof backing or linoleum may be used to cover the working surface of the hood. The fume hood exhaust system should be capable of producing an air flow of about 30 to 60 linear metres per minute across the opening of the fume hood when the shutter is open to the working position. The air passing in the cupboard will, of course, form part of the ventilation of the room and is usually a large fraction of it. Smoke tests should be carried out to ensure that the draught is adequate under all circumstances to prevent radioactive dust and vapours being flown from the fume hood back into the air of the laboratory. The base structure should be so strong as to support a load of 2 240 kg/m^2. The location of the fume hood inside the radiochemical laboratory should be away from window, doors, ventilation outlets and laboratory personnel. Due care should be given when considering the design and erection of exhaust ducts towards ease of replacement as well as minimizing the spread of contamination within buildings during the dismantling operations. For example, the duct length could be as short as possible and single piece and the exhaust fan should be mounted on the outside of the ducting to reduce contamination of the motor and to make it more accessible for maintenance purposes. Centrifugal fans are more suited for this purpose. Provision should be made for the introduction of air filters at a later stage. A piece of ducting needing repairs after long run is best discarded as radioactive waste; this prevents spread of contamination in workshop and open areas. The speed of the air flow should be such that there should be no escape of air into the working place from the fume hood under operating conditions. This may be checked by smoke tests. Good top lighting should be provided in fume cupboards and all bulbs and fittings should be outside the cupboard facilitating easy maintenance with the light passing through a ‘ sealed window ’.

h) *Glove boxes* — At higher levels of activity, the protection given by a fume hood ceases to be adequate and hence it becomes necessary to enclose the active material all the time in a sealed type of box, known as glove box, which is having one or more faces and made of transparent material, such as perspex. These boxes are particularly useful for dry material, of the activity of the order of 1 mCi/g and upwards. The box is fitted with an exhaust fan and operated under a slightly reduced pressure, so as to minimize any probability of leakage of active material into the laboratory. The fan is preceded by a high efficiency filter so as to keep the fan and exhaust ducting as clear as possible. The exhaust air is directly carried into the exhaust ducting and then to the outside. Manipulations inside the glove box are done by means of long rubber gloves sealed into portholes in the sides. Any release of contamination from the glove box into the room is due normally to the moving material, for example, equipment, tools, etc, in and out of the box. However, this may be restricted by the use of a transit box which is a small box mounted on the side of the glove box and having two doors, one opening to the laboratory and the other into the glove box. The transit box helps in keeping the laboratory clean.

j) *Illumination, ventilation and air-conditioning* — To ensure efficient manipulations, adequate illumination of the working place is an important factor. Though fluorescent lighting is usually recommended, disturbances might arise in counting set-ups, due to defective fluorescent lamps. The ventilation should provide 10 to 20 air changes per hour. The ventilating system should aim at preventing the spread of air-borne activity outside the building or from one part of the building to another. It is necessary to supply pure air, which should be filtered to prevent excessive dust from being brought in. The flow of air within the building should always tend to be from the less to the more active areas. Such an air flow will help to prevent the spread of activity into non-active areas. The location of the exhaust outlet shall be at least 1·5 metres above the tallest point of building. There should be no taller buildings in the adjacent areas. Air-conditioning is recommended for counting because of the better performance of the instruments but it is not essential for the entire radiochemical laboratory.

7.4 Type 3 Laboratory

7.4.1 For the higher levels of activity of the order mentioned in Table 2 a specially designed laboratory will be required. Requirements for this type of laboratory are not described in this document.

7.5 Laboratory Techniques and Equipment

7.5.1 *Choice of Process* — The quantity of radicactive material chosen for any specific purpose should not be greater than the minimum dictated by experimental needs. It is preferable to work with solutions rather than dry powdery materials. The manipulation processes selected should be those which avoid excessive transfers from one vessel to another.

7.5.2 *Equipment* — Special equipment consisting of tongs, forceps, trays and for the higher levels of gamma-activity apparatus, with adequate shielding should be provided. All equipment used or handling radioactive materials should be confined to the activity area and should be treated as contaminated.

7.5.3 Containers for active materials should as far as possible incorporate necessary shielding close to the source. Pipetting of solutions and operation of wash bottles should never be performed by mouth, but by means of compression bulbs and by remote handling equipment wherever necessary. Glass-blowing on contaminated apparatus shall be done with special techniques which do not involve mouth operations. Squeeze type wash bottles and propipettes are useful for those operations.

7.5.4 *Storage Cell* — In addition to active areas, the laboratory should have provision for a well designed cubicle for storing radioactive sources. The area should be designed with some understanding of utilization of sources.

7.5.5 *Decontamination Procedures* — In any establishment using radioisotopes, contamination either direct or indirect is unavoidable in spite of the stringent measures adopted to prevent it. The types of contaminations which are common to any radioisotope laboratory are of three types:

a) Personnel contamination,
b) Equipment contamination, and
c) Work area contamination.

Decontamination of each type mentioned above may be achieved by careful manipulation of a set of procedures outlined below:

7.5.5.1 *Personnel decontamination* — Personal cleanliness should be watched in all operations where there is a likelihood of even the slightest contamination; persons working with radioisotopes (including those of low toxicity) should wash their hands thoroughly with detergents before leaving the work area, either temporarily or at the end of the working period. Particular attention should be paid to the finger nails. After washing, the contaminated parts should be checked rigorously for any fixed residual contamination. Table 2 specifies the permissible levels of surface contamination. For instance if washing with detergents and water fails to bring down the level of contamination below permissible level, say in the case of hand, other methods should be tried. One may resort to treatment with suitable chemicals, such as potassium permanganate and sodium bisulphite or EDTA solution. However, chemical treatment should be conducted carefully because this will enhance chances of uptake through porous skin. Even mild abrasions or scrubbing shall be done with soft nylon brush in such a way as not to injure the skin. However, treatment with chemicals shall always be done with utmost discretion depending upon the site of contamination and only under medical supervision. For example, any contamination in the eye or near the eye should be removed only with water and not chemicals. Similarly treatment of face and other sensitive organs should be conducted with greatest caution and on proper supervision of the authorized physician. Care shall be taken to avoid contamination of abrasions, cuts and puncture wounds and any person with any of these handicaps shall not be allowed to work with radioisotope, without proper sealing of the open wound. If skin break or cut occurs while working in an active area, the authorities concerned shall be informed immediately for contamination check-up and further decontamination. Needless to say, a medical officer should be consulted in all cases of contamination of cuts and sores.

TABLE 2 MAXIMUM PERMISSIBLE LEVELS OF SURFACE CONTAMINATION

Sl No.	Details	Maximum Permissible Level	
		Alpha	Beta-Gamma
(1)	(2)	(3)	(4)
1.	General working areas (floor, walls table-tops, equipment, surfaces, etc):		
	a) Transferable contamination:		
	i) Slightly and moderately hazardous	2·5 dpm/cm^2	100 dpm/cm^2
	ii) Highly hazardous	2·5 dpm/cm^2	50 dpm/cm^2
	b) Fixed contamination:		
	i) Slightly and moderately hazardous	2·5 dpm/cm^2	140 dpm/cm^2
	ii) Highly hazardous	2·5 dpm/cm^2	140 dpm/cm^2
2.	Hands* (Total contamination)	200 dpm	4 000 dpm
3.	Skin*	800 dpm	40 dpm/cm^2 (Note 1)
4.	Clothing*:		
	a) Personal	800 dpm	40 dpm/cm^2 (Note 1)
	b) Company issued	2 800 dpm	140 dpm/cm^2 (Note 2)
5.	Shoes:		
	a) Transferable contamination:		
	i) Personal	1 dpm/cm^2	20 dpm/cm^2
	ii) Company issued	2·5 dpm/cm^2	50 dpm/cm^2
	b) Fixed contamination:		
	i) Personal	1 100 dpm	280 dpm/cm^2 (Note 3)
	ii) Company issued	2 800 dpm	700 dpm/cm^2 (Note 2)

NOTE 1 — The total contamination should not exceed 10^6 dpm.

NOTE 2 — The total contamination should not exceed $3 \cdot 5 \times 10^6$ dpm.

NOTE 3 — The total contamination should not exceed $1 \cdot 4 \times 10^6$ dpm.

*No loose contamination is permitted; the levels given are for fixed contamination.

7.5.5.2 *Decontamination of laboratory equipment and work areas* — Any equipment which has been used in connection with any radioactive work should be treated as contaminated unless proved otherwise by a careful survey. The types of decontamination treatment will depend upon the nature of contaminant and upon the type of surface contaminated:

a) Glassware may be cleaned on a routine basis with chromic acid solution. If unsuccessful, other cleaning agents, such as concentrated nitric acid, ammonium citrate, penta sodium triphosphate and ammonium bifluoride should be tried. The solutions used for cleaning should be disposed off adequately as active waste (*see* **8**).

b) All metal objects may be cleaned by washing with a detergent solution followed, if necessary, with dilute nitric acid or a 10 percent solution of sodium citrate or ammonium bifluoride. In the case of stainless steel hydrochloric acid should be avoided as this will result in corrosion leading to greater difficulty in future decontamination work. Brass polish for brass, oxalic acid for rusty surfaces, ammonium citrate, dilute acids and organic solvents are also recommended for decontamination purposes.

c) Though plastic paint surfaces may be decontaminated often successfully by using acetone, trichloroethylene or a 10 percent hydrochloric acid solution, it is advisable to strip off the paint and replace with new coatings.

d) The above mentioned procedures are mostly for wet spillage on various surfaces. However, if a dry contamination occurs on any surface, as a first step in the process of decontamination a vacuum cleaner with a high efficiency filter should be used followed by suitable methods mentioned above.

e) Protective apparel and personal clothing of staff or clothing, bedding of hospital patients who are being treated with radioisotopes shall be monitored regularly. If there is any significant contamination, they should be segregated and stored until the activity has fallen below the safe level as recommended in Table 2, failing which they should be laundered in a special laundering facility or discarded.

7.5.6 *Wash Room and Change Rooms* — Every facility handling radioactivity should be equipped with change rooms at entry and wash room near the working place. The change room is a place where on entry into the building the worker changes into company clothing or overalls as required and goes into the hot areas. At the time of leaving working area, he passes through the change rooms, is monitored and then wears his personal clothing. Change room is also equipped with showers as well as decontamination solution. A change room acts as a barrier against movement of radioactive contamination outside working areas. Wash rooms equipped with showers should be installed in a facility. These would facilitate immediate clean-up in case of sudden spills, or suspected contamination.

8. WASTE DISPOSAL

8.1 Waste problems in a laboratory of Type 1 or 2 are not very significant as in the case of Type 3 laboratory. However, the basic principles do not change in the method of disposal in order to avoid a contamination problem in the neighbourhood, resulting from indiscriminate release. In general, three types of wastes are produced:

a) *Solids* — The solids may comprise filter papers containing precipitates, contaminated glass apparatus, etc. These are collected in polyethylene bags and packaged in suitable containers. If the activity is high enough contact the Bhabha Atomic Research Centre, Trombay, Bombay (AS) for further instructions regarding its handling and safe disposal.

b) *Solutions* — If the solutions contain low activity they may be disposed of in the drain followed by a large flushing of water. The active sources, active spills, etc, may be collected in polyethylene carboys for disposal. In case of high activity refer to Bhabha Atomic Research Centre, Trombay, Bombay (AS). ICRP provides sufficient guidance by fixing limits on the maximum permissible level (MPL) of activity that may be discharged into the environment without endangering the public.

c) *Gases* — Those evolved in the fume hood and other air-borne particulate radioactive dusts are adequately exhausted with suitable ventilation.

8.2 For any major problems connected with safety of handling and disposal of radioactive materials, advice may be sought from Bhabha Atomic Research Centre, Trombay, Bombay (AS).

9. RADIATION MONITORING INSTRUMENTS

9.1 One of the most convenient ways of recording the extent of exposure of personnel is provided by the film badge. This consists of a radio-sensitive film covered with suitable filters. These film badges should be provided for every radiation worker. Details of the film badge service may be obtained from the Officer-in-Charge, Directorate of Radiation Protection, Bhabha Atomic Research Centre, Trombay, Bombay.

9.2 In addition to film badges which are worn on person certain other radiation monitoring instruments are necessary for Type 1 and Type 2 laboratories. For example, a portable battery-operated radiation survey meter, with a thin walled Geiger-Müller counter, suitable for measuring beta and gamma rediations in the low range, and a battery-operated radiation survey meter with ionisation chamber (gun type) for measuring higher levels of beta and gamma radiations are very helpful in assessing the possible extent of radiation exposure. However, in assessing hand contamination a thin walled Geiger-Müller counter connected to the main instrument assembly consisting of a power pack, count rate circuit and 50 microampere meter would prove useful. Surface contamination may be checked up by taking swipe samples of the loose contamination with filter papers and counting the activity in an endwindow Geiger-Müller counter.

9.3 A modified vacuum cleaner assembly of known air intake capacity, for example, 20 litres/min may be used to estimate the air-borne activity. Air is drawn at this flow rate through a millipore filter paper held in a suitable suction head for a known period and the collected activity counted in an endwindow Geiger-Müller counter.

10. GENERAL SAFETY RULES

10.1 A general code of behaviour typical for a radioisotope laboratory has been drawn below in accordance with the provisions of radiation safety. A summary of hazard control procedures has also been presented in the form of a table (*see* Table 3):

a) Laboratory coats shall be worn in the laboratory.
b) Unnecessary materials are not to be brought or allowed to lie in the laboratory.
c) The movement and storage of radioactive material shall be under the control of a responsible person acquainted with safety procedures and regulations.
d) The maintenance of an inventory of radioactive sources is very necessary.
e) Eating, drinking and smoking are not allowed in the laboratory.
f) No mouth operations are allowed, for example, pipettes, wash bottles and labels shall not be put to the mouth.
g) Solid and liquid waste materials shall be put into suitably labelled receptacles.
h) When wearing rubber gloves, disposable tissues should be used for handling taps, switches, etc.
j) Gloves, clothing, apparatus and benches shall be monitored after work with radioactive materials.
k) Radioactive work should not be undertaken by a person having a wound below the wrist.
m) Film badges shall be worn on person and a record of the external dose received by the person shall be maintained.
n) Radiation symbols should be exhibited wherever active sources are being manipulated or stored.

10.2 These rules may of course be modified or augmented to suit special conditions. For instance, spillage might warrant the use of overshoes and perhaps a change of clothing. Areas of particular hazard should be cordoned off with suitable notices restricting entry. It is important to have a sense of awareness while working with radioactive material in accordance with the code of practice. A summary of hazard control is drawn up in Table 3.

TABLE 3 HAZARD CONTROL PROCEDURES

(*Clauses* 10.1 *and* 10.2)

SL No.	HAZARD	EXPOSURE DUE TO	PREVENTIVE MEASURE
(1)	(2)	(3)	(4)
i)	Radiation	Handling of beta and gamma sources (no direct exposure hazard from alpha)	1. Distance 2. Time of exposure 3. Shielding
ii)	Contamination	1. Contaminated apparatus 2. Spills (these are very serious with alpha emitters)	1. Careful technique: a) Providing table tops b) Working in trays c) Use of propipettes d) Use of gloves 2. Good house keeping 3. Containment 4. Frequent monitoring 5. Immediate decontamination
iii)	Ingestion and inhalation	1. Dust 2. Aerosols 3. Spills	1. Containment 2. Avoid dry sources 3. Working in well ventilated place 4. Fume hoods 5. Masks and filters

10.3 Health Surveillance

10.3.1 *Pre-employment Examination* — All new personnel in radiation work shall have a pre-employment medical examination. Notes should be made of the family history, of the previous occupational history, and of previous diagnostic examination or radiation therapy. The examination shall include a complete blood count with determination of erythrocyte and leukocyte levels and a differential white cell count.

10.3.2 *Routine Medical Examination* — Medical examinations should be performed at a frequency depending upon the conditions of the occupational exposure. ICRP recommends that the workers who have been identified as being in conditions of work where doses might exceed 3/10 of the annual maximum permissible doses should be subject to special health supervision and personnel monitoring.

10.4 Personnel Monitoring

10.4.1 *External Radiation* — Doses received as a result of occupational exposures shall be systematically checked with appropriate instruments to ensure that maximum permissible doses are not exceeded and to make it possible to keep individual cumulative dose records.

10.4.2 *Internal Radiation* — Tests should be performed to estimate the total body burden for workers who deal with unsealed radioactive isotopes that may give rise to levels of ingestion or inhalation in excess of the maximum permissible concentrations. Such tests should also be performed where radioisotopes may enter the body through the skin or through skin punctures and open wounds. These tests may require the monitoring of breath and excreta, and the direct determination of the body burden by means of a total body monitor according to circumstances.

11. TRAINING, INDOCTRINATION AND SAFETY SUPERVISION

11.1 An important contributory factor in safety is the training and indoctrination given to the worker in radiation hazards and safety code of practice. For any new installation it is important that the staff should be given lectures and demonstration in the use of personnel monitoring equipment and good housekeeping methods by a trained health physicist. There are regular training facilities with the Bhabha Atomic Research Centre, Trombay, Bombay for imparting the necessary knowledge and practical experience. The trained health physicist or the health supervisor should conduct in turn periodical refresher courses and maintain a record of personal exposures.

11.2 Safety Supervision — The authority in charge of radiochemical laboratory shall identify a technically competent person or persons to provide advice on all relevant aspects of radiation protection and to provide such technical services as required in the application of appropriate recommendation for radiation protection and maintain exposure records as required by the safety code and national radiation safety practices.

12. PROTECTIVE MEASURES

12.1 Equipment — External radiation hazards may be minimized by making use of special equipment, such as long handled forceps, tongs, etc, while manipulating active sources from a distance of 15 to 100 cm. In its simplest form the long handled tongs will have a pistol grip together with a trigger mechanism operating a ‘grip’ which may be used to hold the active source. An additional improvement over the latter one is the provision of a threaded screw which may be screwed up so that the grip remains securely fastened to the radioactive source. Drip trays of stainless steel or plastic, lined with absorbent paper, help to minimize the spread of contamination in case of spills. The tray should be without rough surfaces, or sharp corners, to facilitate easy decontamination. For higher levels of gamma activity, adequate shielding should be provided for containers of active materials and as far as possible incorporate necessary shielding close to the source. All manipulation should be done in a drip tray or in some form of double containers.

12.2 Pipetting of solutions and operations of wash bottles should never be performed by mouth, but by means of compression bulbs, remote handling pipettes, squeeze type wash bottles, etc. Never look down into a beaker or test-tube containing several millicuries of a strong beta emitter. Glass-blowing on contaminated apparatus shall be done with techniques which do not involve mouth operation.

12.3 Placards bearing radiation symbols are required in the laboratory. The placards should also bear health safety instructions and should be put up, wherever radioactive sources are being manipulated or stored.

12.4 Equipment used for handling radioactive materials should be confined to the active area of laboratory.

12.5 Protective Clothing — In any radioisotope laboratory, the type of protective clothing required will depend upon the nature of work. For usual laboratory work (Type 1) the ordinary laboratory coats are quite adequate. If work involves decontamination of equipment, a change of shoes in addition is advisable. Overshoes made of plastic or rubber material may be used.

12.6 Work shall not be carried out with radioactive materials or materials suspected to be carrying contamination, without wearing rubber gloves. Rubber gloves used for handling active materials should not be used for handling other items, even in the active laboratory. Contaminated gloves should be thoroughly washed before taking off. The wearing and removal of the gloves should be in the same way as that of the surgical technique to minimize the contamination of hands. It is necessary to point out here, that while these gloves might provide adequate protection against soft beta rays, they are not adequate against hard beta rays. Heavier rubber gloves are more robust and give some measure of protection against beta radiation; they may be made more comfortable to wear by lining with cotton fabric.

12.7 Respirators —When the concentration of air-borne activity in working atmosphere goes above the maximum permissible levels during any major or minor operation, special precautions have to be taken. These include the wearing of a fully impervious clothing made up of a full rubber suit with boots, gloves and helmet and fresh air is supplied through an airline. Before donning such a wear, a full change of clothing is recommended. However, where the contamination level is not so high and is only occasional, lighter type of suit made of thin plastic material may be used with a simple airline hood. During short periods of emergency a high efficiency respirator is used along with a hood to cover the head. The body as a whole is covered with plastic overalls. In a radioisotope laboratory an accident, such as even a spillage might warrant use of respirators and protective apparel.

12.8 It is necessary to ensure the periodic check-up of handling equipment and examination at frequent intervals of respirators and protective clothing. This would help in keeping them ready for any emergency work.

13. HAZARD CHARACTERISTICS OF SOME COMMON RADIONUCLIDES

13.1 The radiation and hazard characteristics of some commonly used radionuclides are given in Appendix B. All values of MPC quoted are for occupational exposure only. For general public the permissible level is 1/10 of the occupational value.

APPENDIX A

(*Clause* 5.1)

CLASSIFICATION OF RADIOISOTOPES ACCORDING TO RELATIVE RADIOTOXICITY PER UNIT ACTIVITY

Group 1

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Pb-210	Po-210	Ra-223	Ra-226	Ra-228	Ac-227	Th-227	Th-228	Th-230
Pa-231	U-230	U-232	U-233	U-234	Np-237	Pu-238	Pu-239	Pu-240
Pu-241	Pu-242	Am-241	Am-243	Cm-242	Cm-243	Cm-244	Cm-245	Cm-246
Cf-249	Cf-250	Cf-252						

Group 2

Na-22	Cl-36	Ca-45	Sc-46	Mn-54	Co-56	Co-60	Sr-89	Sr-90
Y-91	Zr-95	Ru-106	Ag-110m	Cd-115m	In-114m	Sb-124	Sb-125	Te-127m
Te-129m	I-124	I-126	I-131	I-133	Cs-134	Cs-137	Ba-140	Ce-144
Eu-152 (13 Y)		Eu-154	Tb-160	Tm-170	Hf-181	Ta-182	Ir-192	Tl-204
Bi-207	Bi-210	At-211	Pb-212	Ra-224	AC-228	Pa-230	Th-234	U-236
Bk-249								

Group 3

Be-7	C-14	F-18	Na-24	Cl-38	Si-31	P-32	S-35	A-41
K-42	K-43	Ca-47	Sc-47	Sc-48	V-48	Cr-51	Mn-52	Mn-56
Fe-52	Fe-55	Fe-59	Co-57	Co-58	Ni-63	Ni-65	Cu-64	Zn-65

Group 3 — *Contd*

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Zn-69m	Ga-72	As-73	As-74	As-76	As-77	Se-75	Br-82	Kr-85m
Kr-87	Rb-86	Sr-85	Sr-91	Y-90	Y-92	Y-93	Zr-97	Nb-93m
Nb-95	Mo-99	Tc-96	Tc-97m	Tc-97	Tc-99	Ru-97	Ru-103	Ru-105
Rh-105	Pd-103	Pd-109	Ag-105	Ag-111	Cd-109	Cd-115	In-151m	Sn-113
Sn-125	Sb-122	Te-125m	Te-127	Te-129	Te-131m	Te-132	I-130	I-132
I-134	I-135	Xe-135	Cs-131	Cs-136	Ba-131	La-140	Ce-141	Ce-143
Br-142	Pr-143	Nd-147	Nd-149	Pm-147	Pm-149	Sm-151	Sm-153	Eu-152
Eu-155	Gd-153	Gd-159	Dy-165	Dy-166	Ho-166	Er-169	Er-171	(9·2 hr)
Tm-171	Yb-175	Lu-177	W-181	W-185	W-187	Re-183	Re-186	Re-188
Os-185	Os-191	Os-193	Ir-190	Ir-194	Pt-191	Pt-193	Pt-197	Au-196
Au-198	Au-199	Hg-197	Hg-197m	Hg-203	Tl-200	Tl-201	Tl-202	Pb-203
Bi-206	Bi-212	Rn-220	Rn-222	Th-231	Pa-233	Np-239		

Group 4

H-3	O-15	A-37	Co-58m	Ni-59	Zn-69	Ge-71	Kr-85	Sr-85m
Rb-87	Y-91m	Zr-93	Nb-97	Tc-96m	Tc-99m	Rh-103m	In-113m	I-129
Xe-131m	Xe-133	Cs-134m	Cs-135	Sm-147	Re-187	Os-191m	Pt-193m	Pt-197m
Th-232	Th-Nat	U-235	U-238	U-Nat				

NOTE — IAEA refers to groups 1 to 4 as high toxicity, medium toxicity — upper sub-group A, medium toxicity — lower sub-group B, and low toxicity respectively.

APPENDIX B

(*Clause* 13.1)

HAZARD CHARACTERISTICS OF SOME RADIONUCLIDES

B-1. BARIUM 140 ($_{56}Ba^{140}$)

Occurrence or production: A fission product (parent of La-140).

Production Process	*Activation Cross-Section*	*Other Activities*
U(n, f) Ba-140	—	La-140 (daughter) 40·2 h

Radioactive emission   Beta: 0·48 Mev (40 percent)
1·02 Mev (60 percent)

Gamma: 0·03 Mev*, 0·16 Mev,
0·30 Mev, 0·54 Mev*

(La^{140} activity always present)

Critical organ:
Bone

Maximum permissible body burden:
4 μCi alignment

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*Most abundant gammas.

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ µCi/cc	(M.P.C.)$_a$ µCi/cc
Soluble	CI (LLI)	3×10^{-4}	6×10^{-8}
Insoluble	Bone	2×10^{-3}	$4{\cdot}0 \times 10^{-8}$
	Lung	—	10^{-8}
	GI (LLI)	2×10^{-4}	4×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
12·8 d	65 d	10·7 d

Daily urinary excretion rate: 1 percent (calculated).

Hazard characteristics: K Factor (Ba - 140 + La - 140) 15 r/h at 1 cm/mCi.

B-2. BERYLIUM 7 ($_4Be^7$)

Occurrence or production: Cyclotron production; cosmic ray production.

Production Process	*Activation Cross-Section*	*Other Activities*
C^{12} (p^3, p^3n) Be^7	—	Not known
Li^7 (p, n) Be^7	0·51 b	

Radioactive emission: Gamma: 0·48 Mev (approximately 12 percent) EC*: 100 percent

Critical organ: Total body

Maximum permissible body burden: 600 µCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ µCi/cc	(M.P.C.)$_a$ µCi/cc
Soluble	GI (LLI)	0·02	4×10^{-6}
	Total body	2·0	2×10^{-6}
Insoluble	Lung	—	4×10^{-7}
	GI (LLI)	0·02	3×10^{-6}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
53·6 d	180 d	41 d

Hazard characteristics: K Factor 0·3 r/h at 1 cm/mCi.

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*Emits characteristic Li X-rays 0·052 Kev.

B-3. BROMINE 82 ($_{35}Br^{82}$)

Occurrence or production: Irradiation of ammonium bromide and potassium bromide.

Production Process	*Activation Cross-Section*	*Other Activities*
Br^{81} (n, γ) Br^{82}	3·1 barns	Br^{80m} Br^{80} C^{14}

Radioactive emission		
	Beta:	0·44 Mev (100 percent)
	Gamma:	0·55 Mev (70 percent)
		0·62 Mev (43 percent)
		0·70 Mev (29 percent)
		0·78 Mev (87 percent)
		0·83 Mev (26 percent)
		1·04 Mev (30 percent)
		1·32 Mev (28 percent)
		1·48 Mev (18 percent)

Critical organ: Total body

Maximum permissible body burden: 10 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ μCi/cc	(M.P.C.)$_a$ μCi/cc
Soluble	Total body	3×10^{-3}	4×10^{-7}
	GI (SI)	3×10^{-3}	6×10^{-7}
Insoluble	GI (LLI)	4×10^{-4}	6×10^{-8}
	Lung	—	2×10^{-7}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
1·5 d	8 d	1·3 d

Hazard characteristics: K Factor 14·7 r/h at 1 cm/mCi.

B-4. CAESIUM 137 ($_{35}Cs^{137}$)

Occurrence or production: A fission product.

Production Process	*Activation Cross-Section*	*Other Activities*
U (n, f) Cs^{137}	—	Cs^{134}
Radioactive emission	Beta: 0·61 Mev (92 percent) 1·17 Mev (8 percent) Gamma: 0·662 Mev (82 percent via 2·6 min Ba^{137m}) IC: 10 percent (characteristic Ba X-rays 32 Kev)	

Critical organ:
Total body

Maximum permissible body burden:
30 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ μCi/cc	(M.P.C.)$_a$ μCi/cc
Soluble	Total body	2×10^{-4}	2×10^{-8}
Insoluble	Lung	—	5×10^{-9}
	GI (LLI)	4×10^{-4}	8×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
$1·1 \times 10^4$ d	70 d	70 d

Hazard characteristics: K Factor 3·1 r/h at 1 cm/mCi.

B-5. CALCIUM 45 ($_{20}Ca^{45}$)

Occurrence or production: Reactor irradiation of $CaCO_3$

Production Process	*Activation Cross-Section*	*Other Activities*
Ca^{44} (n, γ) Ca^{45}	0·67 barns	Ca^{47} Ca^{49} Sc^{47} Sc^{49}
Radioactive emission	Beta: 0·25 Mev	

Critical Organ:
Bone

Maximum permissible body burden:
30 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	Bone	9×10^{-5}	10^{-8}
Insoluble	Lung	—	4×10^{-8}
	GI (LLI)	2×10^{-3}	3×10^{-7}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
164 d	$1{\cdot}80 \times 10^4$ d	162 d

B-6. CARBON 14 ($_6C^{14}$)

Occurrence or production: Reactor irradiation of aluminium nitride.

Production Process	*Activation Cross-Section*	*Other Activities*
N^{14} (n, p) C^{14}	1·75 barns	Negligible
Radioactive emission	Beta: 0·155 Mev	

Critical organ: Fat	Maximum permissible body burden: 300 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C)$_a$
		μCi/cc	μCi/cc
Soluble (CO_2)	Fat	8×10^{-3}	10^{-6}
Submersion	Total body	—	10^{-5}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
2×10^6 d	12 d	12 d

B-7. CHROMIUM 51 ($_{24}Cr^{51}$)

Occurrence or production: Reactor irradiation of chromium or potassium chromate.

Production Process	*Activation Cross-Section*	*Other Activities*
Cr^{50} (n, γ) Cr^{51}	13·5 barns	K^{42}
Radioactive emission	EC (100 percent) emits characteristic V X-ray of 5 Kev, Gamma: 0·323 Mev (approximately 8 percent)	

Critical organ: Total body

Maximum permissible body burden: 800 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ μCi/cc	(M.P.C.)$_a$ μCi/cc
Soluble	GI (LLI)	0·02	4×10^{-6}
Insoluble	Lung	—	8×10^{-7}
	GI (LLI)	0·02	3×10^{-6}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
27·8 d	616 d	26·6 d

Hazard characteristics: K Factor 0·18 r/h at 1 cm/mCi.

B-8. COBALT 60 ($_{27}Co^{60}$)

Occurrence or production: Reactor irradiation of cobalt or cobalt chloride in a reactor.

Production Process	*Activation Cross-Section*	*Other Activities*
Co^{59} (n, γ) Co^{60}	36·30 barns	Co^{60m}
Radioactive emission	Beta: 0·306 Mev (100 percent) 1·48 Mev (approximately 0·15 percent) Gamma: 1·17 Mev (100 percent) 1·33 Mev (100 percent)	

Critical organ: Total body

Maximum permissible body burden: 10 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C)$_w$ µCi/cc	(M.P.C.)$_a$ µCi/cc
Soluble	GI (LLI)	5×10^{-4}	10^{-7}
	Total body	10^{-3}	10^{-7}
Insoluble	Lung	—	3×10^{-9}
	G	—	—
	GI (LLI)	3×10^{-4}	6×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
$1·9 \times 10^{3}$ d	9·5 d	9·5 d

Hazard characteristics: K Factor 13·0 r/h at 1 cm/mCi.

B-9. GOLD 198 ($_{79}Au^{198}$)

Occurrence or production: Reactor irradiation of gold.

Production Process	*Activation Cross-Section*	*Other Activities*
Au^{197} (n, γ) Au^{198}	96 barns	Au^{199}
Radioactive emission	Beta: 0·29 Mev (1 percent) 0·96 Mev (99 percent) 1·37 Mev (0·025 percent) Gamma: 0·41 Mev (96·1 percent) 0·68 Mev (1·1 percent) 1·09 Mev (0·26 percent) IC: 3·6 percent	

Critical organ:
Kidney

Maximum permissible body burden:
20 µCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ µCi/cc	(M.P.C.)$_a$ µCi/cc
Soluble	GI (LLI)	5×10^{-4}	10^{-7}
Insoluble	GI (LLI)	5×10^{-4}	8×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
2·7 d	280 d	2·7 d

Hazard characteristics: K Factor 2·3 r/h at 1 cm/mCi.

B-10. IODINE 131 ($_{53}I^{131}$)

Occurrence or production: Iodine-131 is obtained by the irradiation of Te-130 in a reactor as also in the products of nuclear fission of uranium.

Production Process	*Activation Cross-Section*	*Other Activities*
$Te^{130}\ (n, \gamma)\ Te \xrightarrow[B]{138} I^{131}$	0·22 barns	Te-121m Te-123 Te-125 (Te-127m) (Te-129) Xe-131m Te-131m (30 h)

Radioactive emission	Beta:	0·25 Mev (3 percent)
		0·33 Mev (9 percent)
		0·61 Mev (87 percent)
		0·81 Mev (1 percent)
	Gamma:	0·08 Mev (2 percent)
		0·28 Mev (5 percent)
		0·36 Mev (80 percent)
		0·64 Mev (9 percent)
		0·72 Mev (3 percent)
	IC:	4 percent

Critical organ: Thyroid	Maximum permissible body burden: 0·7 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	Thyroid	2×10^{-5}	3×10^{-9}
Insoluble	GI (LLI)	6×10^{-4}	10^{-7}
	Lung	—	10^{-7}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
8·0 d	138 d	7·6 d

Hazard characteristics: K Factor 2·18 r/h at 1 cm/mCi.

B-11. IRON 59 ($_{26}Fe^{59}$)

Occurrence or production: Reactor irradiation of iron or Fe_2O_3 leads to the formation of iron-59.

Production Process	*Activation Cross-Section*	*Other Activities*
Fe-58 (n, γ) Fe-59	0·98 barns	Fe^{58}

Radioactive emission
Beta: 0·27 Mev (46 percent)
0·46 Mev (54 percent)
1·56 Mev (0·3 percent)
Gamma: 0·19 Mev (2·5 percent)
1·10 Mev (56 percent)
1·29 Mev (44 percent)

Critical organ: Spleen

Maximum permissible body burden: 20 µCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		$(M.P.C.)_w$ µCi/cc	$(M.P.C.)_a$ µCi/cc
Soluble	GI (LLI)	6×10^{-4}	10^{-7}
	Spleen	10^{-3}	5×10^{-8}
Insoluble	Lung	—	2×10^{-8}
	GI (LLI)	5×10^{-4}	9×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
45·1 d	600 d	41·9 d

Hazard characteristics: K Factor 6·2 r/h at 1 cm/mCi.

B-12. PHOSPHORUS 32 ($_{15}P^{32}$)

Occurrence or production: Produced in reactors by irradiation of red phosphorus or KH_2PO_4.

Production Process	*Activation Cross-Section*	*Other Activities*
P^{31} (n, γ) P^{32}	0·19 barns	K^{42}
S^{32} (n, p) P^{32}	—	P^{33} S^{35} S^{37}

Radioactive emission
Beta: 1·71 Mev

Critical organ: Bone

Maximum permissible body burden: 6 µCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ µCi/cc	(M.P.C.)$_a$ µCi/cc
Soluble	Bone	2×10^{-4}	2×10^{-8}
Insoluble	Lung	—	3×10^{-8}
	GI (LLI)	2×10^{-4}	4×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
14·3 d	1·155 d	14·1 d

B-13. PLUTONIUM 239 ($_{94}Pu^{239}$)

Occurrence or production: The target is not a specified one. Various chemical forms of uranium may be employed.

Production Process	*Activation Cross-Section*	*Other Activities*
$U^{238}\ (n, \gamma)\ U^{239} \xrightarrow[23\cdot5m]{\beta} Np^{239} \xrightarrow[2\cdot3d]{\beta} Pu^{239}$	2·74 barns	Not known

Radioactive emission

Alpha:
5·09 Mev (10·7 percent)
5·13 Mev (16·8 percent)
5·14 Mev (72·5 percent)

Critical organ:
Bone

Maximum permissible body burden:
0·04 µCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ µCi/cc	(M.P.C.)$_a$ µCi/cc
Soluble	Bone	5×10^{-5}	6×10^{-13}
Insoluble	Lung	—	10^{-11}
	GI (LLI)	3×10^{-4}	5×10^{-8}

Physical Half-Life	*Biological Half-life*	*Effective Half-Life*
$8\cdot9 \times 10^{6}$ d	$7\cdot3 \times 10^{4}$ d	$7\cdot2 \times 10^{4}$ d

B-14. POLONIUM 210 ($_{84}Po^{210}$ RaF)

Occurrence or production: Reactor irradiation of bismuth oxide leads to the formation of polonium-210.

Production Process	*Activation Cross-Section*	*Other Activities*
$Bi^{209}(n,\gamma)Bi \xrightarrow[(5d)\beta]{210} Po^{210}$	0·019 barns	None

Radioactive emission
Alpha: 5·305 Mev (100 percent)
Gamma: 0·8 Mev (0·001 2 percent)

Critical organ: Spleen

Maximum permissible body burden: 0·03 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	Spleen	7×10^{-6}	2×10^{-10}
	Kidney	8×10^{-6}	2×10^{-10}
Insoluble	Lung	—	7×10^{-11}
	GI (LLI)	3×10^{-4}	5×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
138·4 d	60 d	42 d

B-15. POTASSIUM 42 ($_{19}K^{42}$)

Occurrence or production: Reactor irradiation of potassium carbonate or potassium chloride in a reactor.

Production Process	*Activation Cross-Section*	*Other Activities*
$K^{41}(n,\gamma)K^{42}$	1·1 barns	P^{32} S^{35} Cl^{36} Cl^{38}

Radioactive emission
Beta: 2·0 Mev (18 percent)
3·6 Mev (82 percent)
Gamma: 1·53 Mev (18 percent)

Critical organ: Total body

Maximum permissible body burden: 10 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	GI (S)	3×10^{-3}	7×10^{-7}
	GI (LLI)	2×10^{-4}	4×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
0·52 d	58 d	0·52 d

Hazard characteristics: K Factor 1·37 r/h at 1 cm/mCi.

B-16. RADIUM 226 ($_{88}Ra^{226}$)

Occurrence or production: It is a naturally occurring radioisotope available in significant quantities in pitchblende.

Production Process	*Activation Cross-Section*	*Other Activities*
Natural radioisotope	—	Daughter products of the U-Ra series

Radioactive emission

Alpha: 4·589 (5·7 percent)
4·777 (94·3 percent)
Gamma: 0·188 (approximately 4 percent)
IC: 2 percent
Activity due to Radon and daughters present

Critical organ: Bone

Maximum permissible body burden: 0·1 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	Bone	10^{-7}	10^{-11}
Insoluble	GI (LLI)	3×10^{-4}	6×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-life*
$5·9 \times 10^5$ d	$1·64 \times 10^4$ d	$1·64 \times 10^4$ d

Hazard characteristics: K Factor 8·25 r/h at 1 cm/mCi.

B-17. SILVER 110 m ($_{47}Ag^{110m}$)

Occurrence or production: Irradiation of silver in a reactor leads to the formation of Ag-110.

Production Process	*Activation Cross-Section*	*Other Activities*
Ag^{109} (n, γ) Ag^{110m}	3·2 barns	None

Radioactive emission		
	Beta:	0·087 Mev (55 percent)
		0·53 Mev (43 percent)
		2·87 Mev (2 percent via 24 sec Ag-110)
	Gamma:	0·66 Mev (94 percent)
		0·68 Mev (12 percent)
		0·71 Mev (17 percent)
		0·74 Mev (5 percent)
		0·76 Mev (21 percent)
		0·81 Mev (8 percent)
		0·88 Mev (69 percent)
		0·94 Mev (29 percent)
		1·38 Mev (26 percent)
		1·48 Mev (5 percent)
		1·51 Mev (14 percent)

IT: [0·116 Mev (approximately 0 percent)]
(IC : 2 percent to 24 sec Ag-110)

Critical organ:
Kidney

Maximum permissible body burden:
10 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	GI (LLI)	3×10^{-4}	7×10^{-8}
Insoluble	Lung	—	3×10^{-9}
	GI (LLI)	3×10^{-4}	5×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
270 d	10 d	10 d

Hazard characteristics: Nil.

B-18. SODIUM 24 ($_{11}Na^{24}$)

Occurrence or production: Reactor irradiation of sodium carbonate, sodium chloride or sodium bicarbonate yields sodium-24.

Production Process	*Activation Cross-Section*	*Other Activities*
Na^{23} (n, γ) Na^{24}	0·536 barns	Cl^{36} Cl^{38} P^{32} S^{35}

Radioactive emission	Beta:	1·39 Mev (100 percent)
	Gamma:	1·37 Mev (100 percent) 2·76 Mev (100 percent)

Critical organ: Total body

Maximum permissible body burden: 7 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ μCi/cc	(M.P.C.)$_a$ μCi/cc
Soluble	GI (SI)	2×10^{-3}	4×10^{-7}
Insoluble	GI (LLI)	3×10^{-4}	5×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
0·63 d	11 d	0·6 d

Hazard characteristics: K Factor 18·4 r/h at 1 cm/mCi.

B-19. STRONTIUM 90 ($_{38}Sr^{90}$)

Occurrence or production: Strontium-90 is a fission product.

Production Process	*Activation Cross-Section*	*Other Activities*
U (n, f) Sr^{90}	—	Sr^{89} Y^{90}

Radioactive emission	Beta: 0·54 Mev Y^{90} $-\beta$ 2·26 Mev

Critical organ: Bone

Maximum permissible body burden: 2 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	Bone	4×10^{-6}	4×10^{-10}
Insoluble	Lung	—	2×10^{-9}
	GI (LLI)	4×10^{-4}	6×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
10^4 d	$1{\cdot}8 \times 10^4$ d	$6{\cdot}4 \times 10^3$ d

Hazard characteristics: Mostly in equilibrium with Y^{90} (T-1/2 64·4 h — Mev β 2·2).

B-20. SULPHUR 35 ($_{16}S^{35}$)

Occurrence or production: Obtained by irradiation of sulphur or potassium chloride in a reactor.

Production Process	*Activation Cross-Section*	*Other Activities*	
S^{34} (n, γ) S^{35}	0·26 barns	P^{32}	S^{37}
Cl^{35} (n, p) S^{35}	0·19 barns	Cl^{38}	P^{32}
		Na^{24}	

Radioactive emission: Beta: 0·167 Mev

Critical organ: Testis

Maximum permissible body burden: 90 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	Testis	6×10^{-4}	9×10^{-8}
Insoluble	GI (LLI)	3×10^{-3}	5×10^{-7}
	Lung	—	9×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
87·1 d	623 d	76·4 d

B-21. THORIUM 232, NATURAL

Occurrence or production: This is a naturally occurring radioisotope abundantly available in monazite.

Production Process	*Activation Cross-Section*	*Other Activities*
Natural radioisotope	—	MsThI (Ra^{228}) and daughter

Radioactive emission	Alpha: 4·007 Mev (100 percent) MsThII (Ac^{228}) 6·13 h IC: 24 percent

Critical organ:	Maximum permissible body burden:
Bone	0·04 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C. $)_w$	(M.P.C. $)_a$
		μCi/cc	μCi/cc
Soluble	Bone	2×10^{-5}	7×10^{-13}
Insoluble	Lung	—	4×10^{-12}
	GI (LLI)	4×10^{-4}	7×10^{-8}

Physical Half-Life (Th^{232})	*Biological Half-Life*	*Effective Half-Life*
$5{\cdot}1 \times 10^{12}$ d	$7{\cdot}3 \times 10^{4}$ d	$7{\cdot}3 \times 10^{4}$ d

B-22. TRITIUM ($_1H^3$)

Occurrence or production: Activation of lithium leads to the formation of tritium.

Production Process	*Activation Cross-Section*	*Other Activities*
Li^6 (n, α) H^3	0·028 barns	None

Radioactive emission	Beta: 0·018 Mev

Critical organ:	Maximum permissible body burden:
(HTO or $H^3{}_2O$) body tissue	10^3 μCi
Sol (total body)	2×10^3 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble HTO or $H^3{}_2O$	Body tissue	0·03	2×10^{-6}
	Total body	0·05	2×10^{-6}
$H^3{}_2$ (submersion)	Skin (submersion)	—	4×10^{-4}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
$4·5 \times 10^3$ d	12 d	12 d

B-23. URANIUM, NATURAL

Occurrence or production: Occurs naturally.

Production Process	*Activation Cross-Section*	*Other Activities*
Natural radioisotope	—	Decay products
U^{238} (99·24 percent)	—	—
U^{235} (0·071 4 percent)	—	—
U^{234} (0·040 percent)	—	—

Radioactive emission Alpha: 4·2 Mev (100 percent)

IC: 23 percent

Critical organ: Kidney

Maximum permissible body burden: 5×10^{-3} μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$	(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	GI (LLI)	2×10^{-4}	4×10^{-8}
	Kidney	6×10^{-4}	3×10^{-11}
Insoluble	Lung	—	2×10^{-11}
	GI (LLI)	2×10^{-4}	3×10^{-8}

Physical Half-Life (U^{238}—U^{234})	*Biological Half-Life*	*Effective Half-Life*
$1·6 \times 10^{12}$ d	15 d	15 d

B-24. ZINC 65 ($_{30}Zn^{65}$)

Occurrence or production: Reactor irradiation of zinc leads to formation of zinc-65.

Production Process	*Activation Cross-Section*	*Other Activities*
Zn^{64} (n, γ) Zn^{65}	0·44 barns	Zn^{69} Zn^{69m}

Radioactive emission
EC Beta: EC (98·5 percent)
β+0·325 Mev (1·5 percent)
Gamma: 1·11 Mev (45 percent)
Emits characteristics Cu X-rays 8·0 Kev
2·5 Mev gamma rays emitted when a positron is emitted.

Critical organ: Total body

Maximum permissible body burden: 60 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week* (M.P.C.)$_w$	
			(M.P.C.)$_a$
		μCi/cc	μCi/cc
Soluble	Total body	10^{-3}	4×10^{-8}
	Prostate	10^{-3}	4×10^{-8}
Insoluble	Lung	—	2×10^{-8}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
245 d	933 d	194 d

Hazard characteristics: K Factor 2·7 r/h at 1 cm/mCi.

B-25. ZIRCONIUM 95 ($_{40}Zr^{95}$)

Occurrence or production: Reactor irradiation of zirconium dioxide in a reactor yields Zr-95 besides occurring in the fission products.

Production Process	*Activation Cross-Section*	*Other Activities*
Zr^{94} (n, γ) Zr^{95}	0·09 barns	Zr^{97} Nb^{97} Nb^{95} daughter Hf^{175} Hf^{181} (from impurities)

Production Process *Activation Cross-Section* *Other Activities*

Radioactive emission	Beta:	0·360 Mev (approximately 43 percent)
		0·40 Mev (approximately 35 percent)
		0·88 Mev (2 percent)
	Gamma:	0·72 Mev (approximately 55 percent)
		0·75 Mev (approximately 48 percent)
		0·23 Mev (0 percent via 90 h Nb-95m)
	IC:	2 percent

Critical organ: Total body

Maximum permissible body burden: 20 μCi

Soluble or Insoluble	*Organ of Reference*	*M.P.C. for 168 h/week*	
		(M.P.C.)$_w$ μCi/cc	(M.P.C.)$_a$ μCi/cc
Soluble	GI (LLI)	6×10^{-4}	10^{-7}
	Total body	1·0	4×10^{-8}
Insoluble	Lung	—	10^{-8}
	GI (LLI)	6×10^{-4}	10^{-7}

Physical Half-Life	*Biological Half-Life*	*Effective Half-Life*
63·3 d	450 d	55·5 d

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- Chemicals, organic (miscellaneous)
- Coal and coke
- Coal carbonization products
- Coated fabrics
- Cosmetics and toilet goods
- Dental materials
- Drying oils
- Dye intermediates
- Electroplating chemicals
- Explosive and pyrotechnic materials
- Fertilizers
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